Evaluation of climate change impacts and adaptation strategies on rainfed rice production in Songkhram River Basin, Thailand

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HIGHLIGHTS

- Top down and bottom up approach was used to evaluate adaptation strategies to climate change for rice production
- Rainfed rice yield is expected to decrease in future due to climate change
- Four adaptation options for rice production were identified through farmers' survey
- Irrigation, as one of the adaptation options, can increase rainfed rice yield to its potential level under climate change

GRAPHICAL ABSTRACT
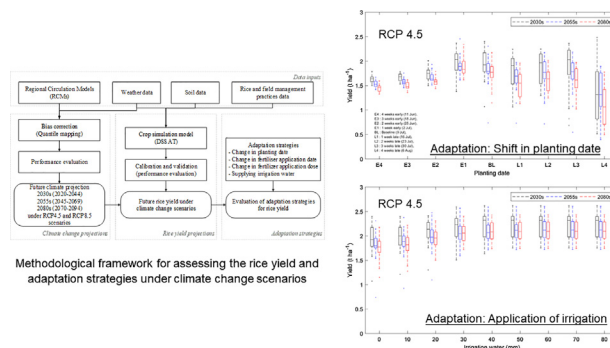
Methodological framework for assessing the rice yield and adaptation strategies under climate change scenarios

ABSTRACT

This study investigates rice yield and evaluates potential adaptation measures on field management practices for rainfed rice production under climate change scenarios in the Songkhram River Basin, Thailand. The top-down and bottom-up approaches are combined to evaluate the future climate conditions in the Songkhram River Basin and identify adaptation strategies respectively. An ensemble of four Regional Climate Models (RCMs) bias-corrected using the Quantile Mapping technique was used to project the future climate under two climate change scenarios (RCP4.5 and RCP8.5). The DSSAT crop simulation model was used to simulate rice yield and evaluate the impacts of climate change on rice yield, as well as the feasibility of four adaptation options, which were solicited from four hundred farmers through questionnaire surveys in the basin. The strategies include (i) change in planting date, (ii) change in fertiliser application date, (iii) change in fertiliser application dose, and (iv) supplying irrigation water. Based on the model results, future maximum and minimum temperatures are expected to increase by 2.8 and 3.2 °C respectively under RCP8.5 scenario for 2080s. Although annual rainfall may be unchanged, rainfall patterns will shift earlier in future. Evaluation of adaptation strategies suggest that supplying irrigation water under RCP4.5 and RCP8.5 scenarios respectively are the best strategies to increase rice yield under climate change scenarios. Change in fertiliser application date and change in planting date can increase the future rice yield by 12 and 8%, respectively under RCP4.5 scenario for 2080s. Adjusting the fertiliser application dose may however reduce future rice yield. Although supplying irrigation water can aid the production of rainfed rice, other concerns such as the source of water are involved. The feasibility of adaptation actions would depend largely on available resources and mindset of farmers. Further work is warranted in exploring a combination of adaptation strategies and management plans to combat the adverse impacts of climate change.

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1. Introduction

Food security has been threatened by several factors and is expected to face more challenges in the future. Climate change is one of the factors, which includes temperature rise, rainfall variability, and increased occurrences of disasters such as floods and droughts (Arunrat and Pumijumnong, 2015). Rice production is one of the major contributors of food security in Thailand. Rice field occupies an area of approximately 9.38 million hectares (18% of Thailand area) and producing 25.24 million tons of rice in 2017 (OAE, 2018). The population in Thailand is gradually growing (NESDB, 2018), increasing food demand. As a result of the decreasing rice field area in Thailand (OAE, 2016), the capacity of rice production in Thailand would nearly fail to meet the minimum level of domestic demand (Arunrat and Pumijumnong, 2015). Moreover, rice production in Thailand is expected to vary in the face of climate change. Fifth assessment report of IPCC highlighted that the global mean surface temperatures are expected to rise up to 4.8 °C by the end of the 21st century, and global precipitation can be both increased and decreased depending on latitudes (IPCC, 2014). Several studies projected that Thailand will be warmer and rainfall become more variable in future (Shrestha et al., 2017; Chinvanno and S.A.S.R., 2009).

Northeast Thailand has the largest rice field area in Thailand, with about 63% of total rice field area in the country. Thai Jasmine ("Kao Dok Mali 105" or "KDML105") rice variety is grown in about 66% of the rice field area in the Northeast region due to suitable climate and geography (Rice Department, 2016). KDML105 is a photoperiod sensitive variety which grows during wet season (planting in June–July and harvesting in November). Irrigation infrastructure covers only 22% of the agriculture area in Thailand (Arunrat and Pumijumnong, 2015) hence rice is mainly grown under rainy conditions. Change in climate has brought negative impacts to agricultural production throughout the world, including many areas in Thailand. Most studies agree that rice production will decline in the future due to rise in temperature and decrease in rainfall (Arunrat and Pumijumnong, 2015; Babel et al., 2011). However, some results were inconsistent due to different crop simulation models, field management practices, and rice varieties studied. Decline in future rice production is mainly expected due to change in rice growth period and increase in crop water requirements. Shrestha et al. (2017) and Babel et al. (2011) found that climate change can reduce the rice production in northeast Thailand. The study by Mainuddin et al. (2013) found that climate change can both increase and decrease rainfed rice production in lower Mekong basin. Climate change does not affect only rice yield, it will also affect the crop water requirement and crop water productivity (Boonwichai et al., 2018). Higher temperatures can decrease seed set and grain yield in rice (Wongchalee et al., 2015), and decreasing rainfall combined with increasing potential evapotranspiration can increase the rice irrigation water requirement, which affects rice production (De Silva et al., 2007).

The degree of impact from climate change on rice production depends on the adaptability of each community. Adaptation strategies can greatly reduce the magnitude of impacts on rice production under climate change conditions. Babel et al. (2011) suggested that planting dates alteration and proper nutrient management can mitigate the effect of climate change on rice production in northeast Thailand. The changing planting date, reduction in fertility stress and supplementary irrigation were evaluated in the lower Mekong basin (Mainuddin et al., 2013).

Many studies have reported the impacts of climate change on rice production in Thailand, but only few have provided adaptation strategies to offset the negative impacts of climate change. In this study, the top-down and bottom-up approaches are combined through evaluating the future climate conditions in the Songkhram River Basin and identifying site-specific adaptation strategies respectively. The focus of the study is to formulate plausible adaptation strategies to the impending problem of food security in Thailand through understanding potential impacts of climate change on the basin and evaluating adaptation options proposed by local stakeholders (i.e. the farmers). This study evaluates climate change impacts on KDML105 rice production under future climate scenarios: RCP4.5 (the intermediate stabilization state), and RCP8.5 (the highest greenhouse gas emission state) scenarios for three future periods (2030s: 2020–2044, 2055s: 2045–2069 and 2080s: 2070–2094) and assesses four potential adaptation strategies at the field scale. The DSSAT v4.6 crop simulation model was employed to study strategies including (i) change in planting date, (ii) change in fertiliser application date, (iii) change in fertiliser application dose, and (iv) supplying irrigation water in the Songkhram River Basin, Thailand. The outcomes of the study will help policymakers and researchers in planning future field management practices for rice fields for more efficient adaptation under climate change conditions.

This paper is organised in four sections. In the following, Section 2 introduces the dataset used and the methodology adopted in this study. Section 3 highlights the results from the study and discusses the adaptation strategies proposed. Finally, the main findings drawn from this study and future research directions are summarized in Section 4.

2. Materials and methods

2.1. Study area

Songkhram River Basin is the second largest basin in Northeast Thailand, and a sub basin of the Mekong River Basin. It is located in the Northeast part of Thailand, between latitude 17°00′ N and 18°25′ N, longitude 103°10′ E and 104°30′ E. It has a catchment area of approximately 13,215 km^2, covering five provinces including Bung Kan, Nakhon Phanom, Nong Khai, Sakon Nakhon and Udon Thani.

The Songkhram river is the tributary of the Mekong river. It originates at Phu Phan mountain between Udon Thani and Sakon Nakhon provinces, flows through Nong Khai, Bung Kan, and flows into the Mekong river in Tha Uthen district, Nakhon Phanom province, with 420 km length. The basin has a tropical climate, the Thai Meteorological Department presented the average temperature ranging from 21.1 °C to 33.1 °C, and an average annual rainfall varying from 1122 mm to 1705 mm during 1980–2004. The location of meteorological stations and land use in the basin show in Fig. 1. The Land Development Department presented that the total rice field area in the basin in 2013 is 45% of the catchment area, with rice as the main crop. There are two main rice growing seasons: major season from June to November, and second season from January to May. Rice production in the basin depends mainly on rainfall. The Office of Agricultural Economics presented that the average major rice yield in the basin was 2.16 t ha^{-1} during 2007–2015.

2.2. Data collection

2.2.1. Meteorological data

The observed meteorological data were obtained from the Thai Meteorological Department (TMD). Six temperature stations; namely Sakon Nakhon, Sakon Nakhon Agromet, Nakhon Phanom, Nakhon Phanom Agromet, Nong Khai, and Udon Thani; and eight rain gauge stations; namely So Pisai, Seka, Ban Doong, Vanorn Niwat, Si Songkhram, Song Dao, Punna Nikorm, and Phu Phan National Park; were used to represent the climate in the basin for projecting future climate based on the period 1980–2004. The weather data from 2009 to 2016 were used for calibration and validation of the DSSAT crop simulation model. Missing temperature data were filled by linear interpolation technique, and missing rainfall data were filled based on APHRODITE's daily gridded precipitation dataset (http://www.chikyu.ac.jp/precip/).

2.2.2. Regional Climate Models (RCMs)

Four Regional Climate Models (RCMs) were selected on the basis of their performance and have been recently used in Thailand by
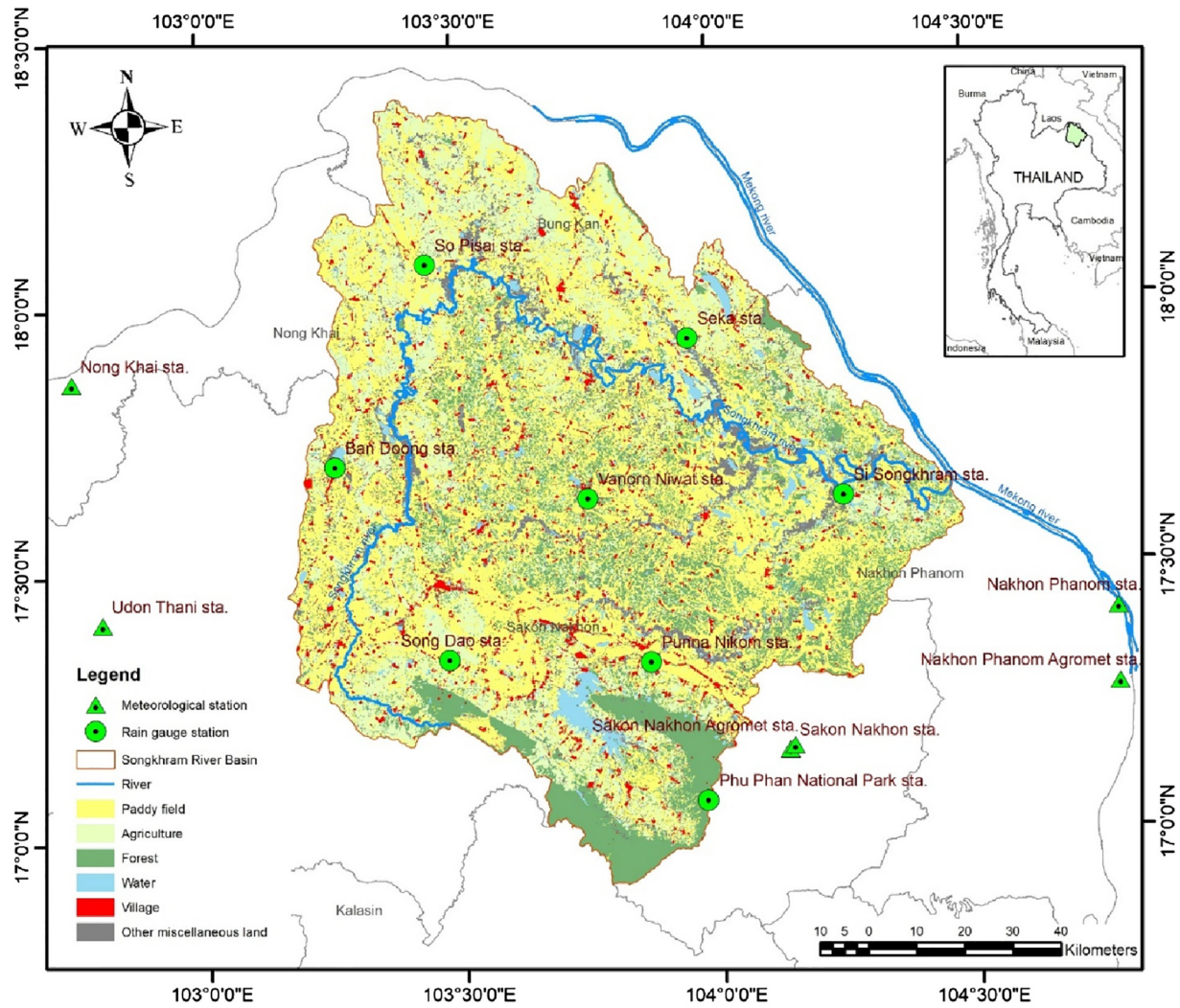
Fig. 1. Location of meteorological stations and land use in Songkhram River Basin, Thailand.

Boonwichai et al., 2018 and Shrestha et al., 2017, 2018 for projecting future climate in the basin (Table 1). Two Representative Concentration Pathways (RCP), RCP4.5 (CO_2 concentrations between 580 and 720 ppm.) which is an intermediate stabilization pathway where radiative forcing is approximately 4.5 W m^{-2} after 2100, and RCP8.5 (CO_2 concentrations higher than 1000 ppm) that radiative forcing reaches >8.5 W m^{-2} after 2100 were selected to represent intermediate and very high greenhouse gas concentrations, respectively. The selected four RCMs with 0.5° latitude x 0.5° longitude spatial resolution are available at Coordinated Regional Climate Downscaling Experiment (CORDEX) (http://cordex.org/).

2.2.3. Rice data and agronomic management practice

Rice and its agronomic management practices data such as rice variety, planting date, planting methods, fertiliser application date and dose, harvesting date, and rice yield were obtained from rice experimental

Table 1
Selected Regional Circulation Models (RCMs) to project the future climate under climate change scenarios in Songkhram River Basin.

RCM	Institute	Driving GCM	Spatial resolution (latitude × longitude)
CCAM: Cubic Conformal Atmospheric Model	CSIRO: Commonwealth Scientific and Industrial Research Organization	ACCESS1.0: The Australian Community Climate and Earth System Simulator Coupled Model	0.5° × 0.5°
CCAM: Cubic Conformal Atmospheric Model	CSIRO: Commonwealth Scientific and Industrial Research Organization	CNRM-CM5: The Center National de Recherches Meteorologiques	0.5° × 0.5°
CCAM: Cubic Conformal Atmospheric Model	CSIRO: Commonwealth Scientific and Industrial Research Organization	MPI-ESM-LR: The Max-Planck-Institut für Meteorologie - Earth System Model running on low resolution grid	0.5° × 0.5°
RCA4: The Rossby Center Regional Climate model	SMHI: The Swedish Meteorological and Hydrological Institute	EC-EARTH: The European Center – Earth model	0.5° × 0.5°

Table 2
Characteristics of KDML105 rice variety in the Songkhram River Basin.

Characteristics	Unit	Value
Planting date	Date	9th July
Fertiliser application date	Date	20th September
Flowering date	Date	20th October
Harvesting date	Date	18th November
Fertiliser application	kg ha^{-1}	90 (mixed NPK 16:16:8)
Planting density	m^{-2}	16
Average yield	t ha^{-1}	1.97

fields at Sakon Nakhon Rice Research Center in Thailand as they are not available in fields. Table 2 represents the characteristics of KDML105 rice variety for study. The data from 2009 to 2016 are used to represent the rice production in the basin. Rice experimental field in the rice center is mostly located on Roi Et series (Buddhaboon et al., 2004). The study assumed that the field management practices in the fields are same as in the center, and the soil for rice field in the basin is homogeneous soils.

The methodology adopted to achieve the research objectives is described in Fig. 2. The top-down approach is used for climate change projection and impact assessment on rainfed rice yield. The quantile mapping technique was used to bias correct the climate data of RCMs for future climate projections under RCP4.5 and RCP8.5 scenarios. The DSSAT version 4.6 crop simulation model was calibrated with data from 2009 to 2012 and validated with data from 2013 to 2016 for projecting the rice production under climate change scenarios for three future periods (2030s, 2055s and 2080s). The bottom-up approach is used for understanding the current rice production situations and adaptation measures in the basin. The adaptation strategies proposed by the farmers in the basin were evaluated.

2.3. Climate change scenarios

Future climate was projected based on four selected RCMs for the three future periods (2030s, 2055s and 2080s) under RCP4.5 and RCP8.5 climate change scenarios. The years 2020–2044 are labelled as the 2030s, 2045–2069 as the 2055s, and 2070–2094 as the 2080s. The study considered only three climate variables including maximum and minimum temperatures, and rainfall. The quantile mapping technique (QM) was applied for correcting the selected RCMs. QM reduces biases

of daily temperature and precipitation by roughly one order of magnitude (Themeßl et al., 2012), and it is better than other methods in very good correction of peak values, especially the 90th percentile (M'Po et al., 2016). The QM is a mapping between two cumulative distribution functions (CDFs); RCMs data and observed data (Themeßl et al., 2012). It can effectively correct the historical climate model data with observed data using the mean, standard deviation, and magnitude (Fang et al., 2015). QM can be expressed in terms of ecdf:

$$P_{corr} = ecdf^{-1}{}_{obs} \left(ecdf_{rcm} \left(P_{rcm} \right) \right) \tag{1}$$

where P_{rcm} is obtained by relating the RCMs data, ecdf is cumulative distribution functions, $ecdf^{-1}$ is inverse cumulative distribution functions, obs is the observed data, rcm is the RCMs data, and P_{corr} is the corrected RCMs data. The coefficient of determination (R^2), mean, annual rainfall and standard deviation (SD) were considered to evaluate the performance of the bias correction.

2.4. Crop simulation model

Decision Support System for Agrotechnology Transfer (DSSAT) version 4.6 crop growth simulation model (Hoogenboom et al., 2015; Jones et al., 2003) was applied to simulate future rice yield under climate change scenarios. DSSAT model has recently been beneficially used in worldwide for different crop growth simulations such as rice, maize and cassava for simulating the potential impact of climate change on crop production. The model has been successfully adapted for simulating rice growth and yield in Thailand (Shrestha et al., 2017; Buddhaboon et al., 2004). Babel et al. (2011) also used the DSSAT model to evaluate the potential adaptation measures for rice yield under climate change scenarios in Northeast Thailand.

DSSAT simulates crop growth and yield as a function of the soil-plant-atmosphere dynamics using morphological and physical characteristics. The genetic coefficients in genotype input file are mainly based on photoperiod sensitivity, grain filling duration, gain weight, temperature tolerant etc. The model requires four sets of data as inputs. First, weather data including daily solar radiation, maximum and minimum temperature, and rainfall. The daily temperature and rainfall data were collected from TMD for current weather, and RCMs used as future climate. Daily solar radiation was estimated based on temperature and extraterrestrial radiation (Allen et al., 1998; Hargreaves and Samani, 1985). Second, soil data such as soil properties, nutrient, and drainage
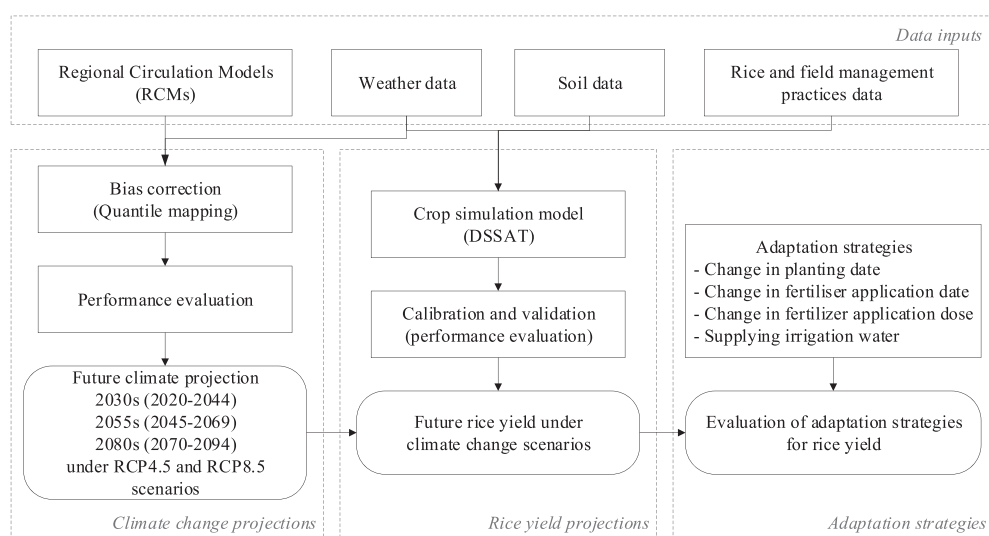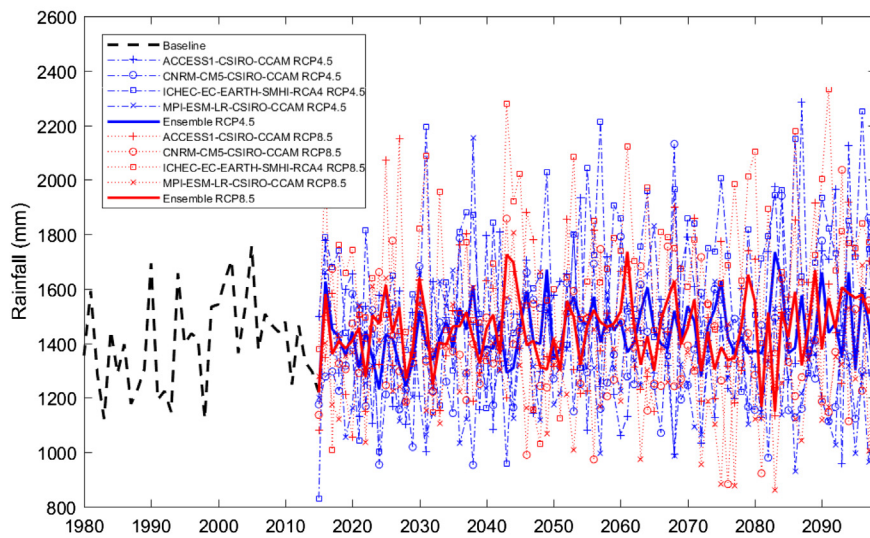

Fig. 2. Methodological framework for assessing the future rice yield and adaptation strategies under climate change scenarios for KDML105 rice variety during rainfed rice season under RCP4.5 and RCP8.5 scenarios for three future periods (2030s, 2055s and 2080s).
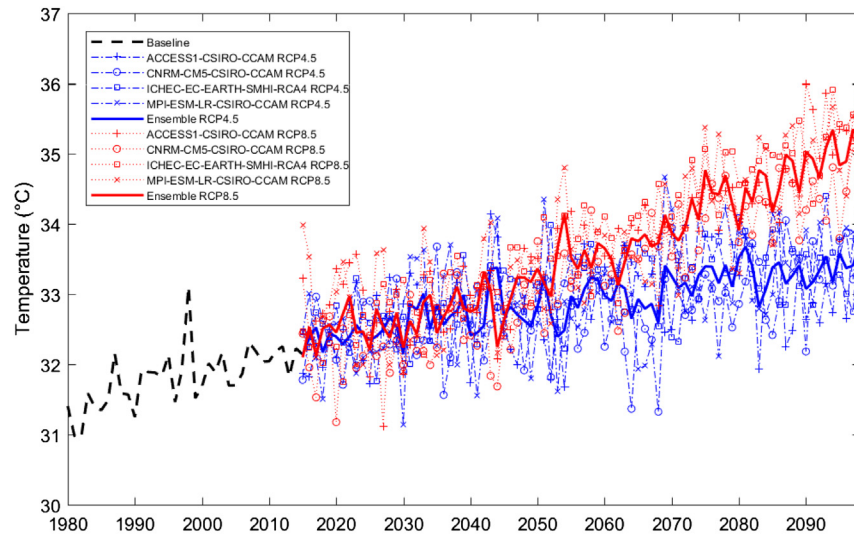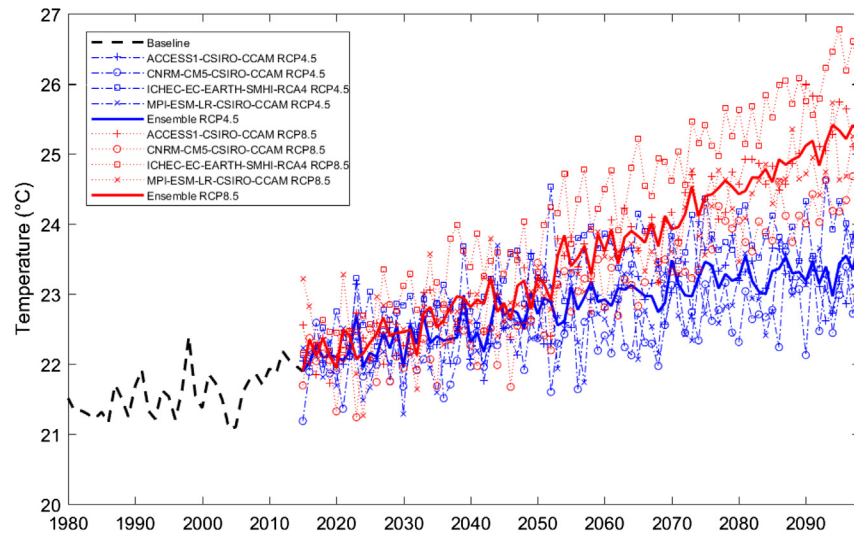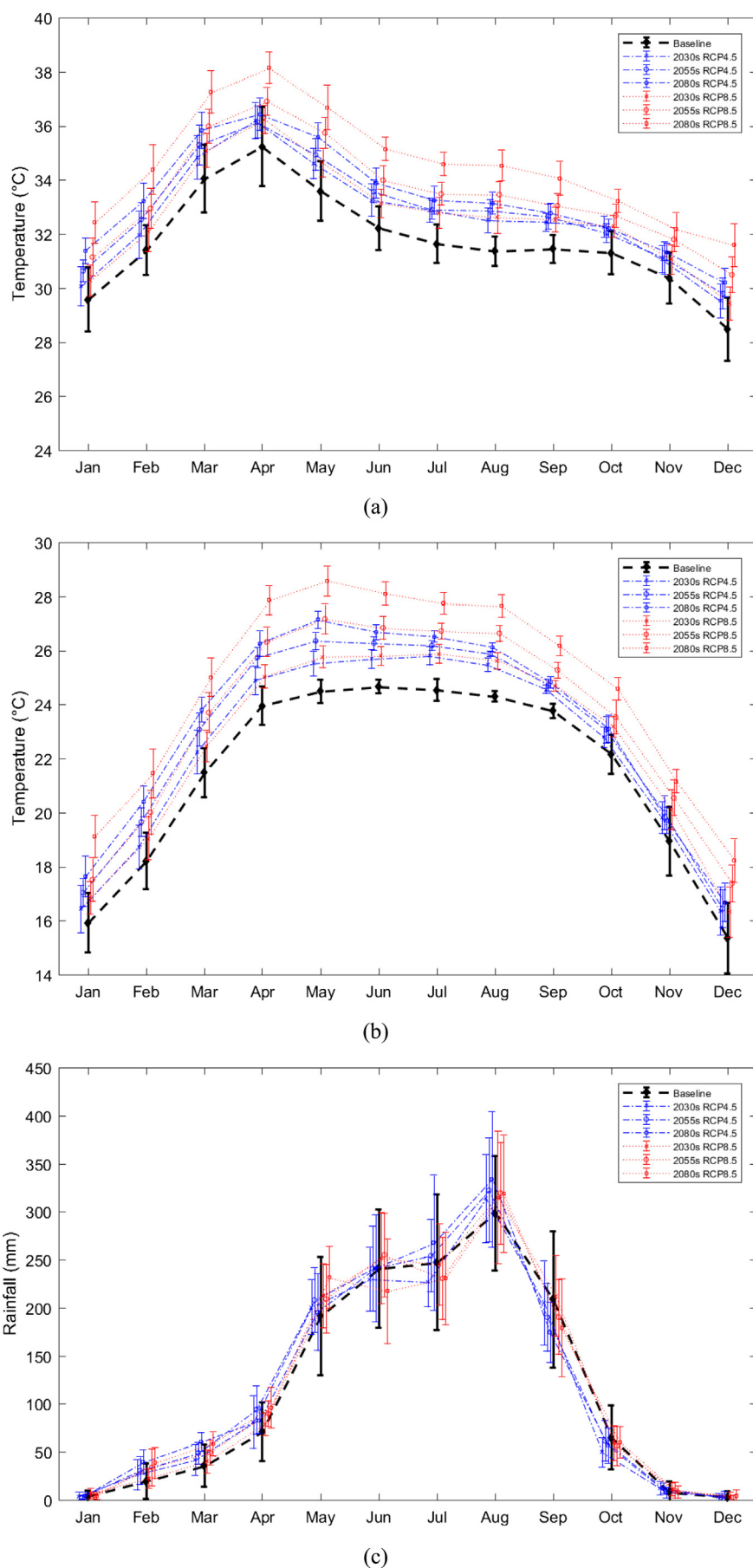
Fig. 3. Historical and projected annual (a) maximum temperature, (b) minimum temperature, and (c) rainfall under RCP4.5 and RCP8.5 scenarios.

Fig. 4. Historical and projected monthly (a) maximum temperature, (b) minimum temperature, and (c) rainfall under RCP4.5 and RCP8.5 scenarios.

Table 3
Genetic coefficients for KDML105 rice variety.

Genetic coefficient	Description	Value	T stat	p-Value
P1	Basic vegetative phase of the plant	502.3	7.40	0.0000*
P2R	Photoperiod sensitivity in panicle initiation	1233.0	−13.76	0.0000*
P5	Grain filling duration	386.5	−77.14	0.0000*
P2O	Critical photoperiod of development occurring at a maximum rate	12.7	−0.23	0.8253
G1	Potential spikelet number coefficient	45.7	29.18	0.0000*
G2	Single grain weight	0.0270	22.94	0.0000*
G3	Tillering coefficient	1.00	−19.17	0.0000*
G4	Temperature tolerant coefficient	0.95	−3.87	0.0026*

* Values significant with respect to a p-value of 0.05.

were obtained from the Land Development Department (LDD). Third, field management practices such as planting date, planting density, and fertiliser application. Last, rice experiment data such as rice variety. There are two main rice seasons: major (rainfed) and second (irrigated). The study considered only the major rice season. Although several rice varieties are grown in rainfed seasons, the study considered only the Thai Jasmine or KDML105 rice variety. Since records for rice and field management practice were not available at the field, the situation in the basin is represented by data obtained from the paddy experiment fields in the Sakon Nakhon Rice Research Center. It is assumed that the soil in the paddy fields is uniform (i.e. Roi Et soil series throughout the column), and that field management practices will remain unchanged in the future.

2.5. Calibration and validation of crop simulation model

Rice experiment data from Sakon Nakhon Rice Research Center are used for calibrating and validating the DSSAT model. Calibration was conducted for the period 2009–2012, and the period of 2013–2016 was used for validation. The study considered only KDML105 rice variety which is suitable for growth during wet season (June to November). The model performance was evaluated based on the following commonly-used statistical parameters: coefficient of determination (R^2), mean, root mean square error (RMSE), Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and RMSE-observations standard deviation ratio (RSR). The ensemble of future climate models was used to project the future rice production under climate change scenarios for 2030s, 2055s and 2080s.

2.6. Adaptation measures

Adaptation strategies are required to reduce negative effects of climate change on rice production. A questionnaire survey with a simple random-sampling technique was conducted for understanding the farmers' perception on impacts of climate change and adaptation measures in the basin. A sample size of four hundred responses was calculated using the Taro Yamane formula (Yamane, 1973) at a 95% confidence level (Section B in supplementary material). The four most recommended adaptation strategies were selected for performance evaluation (Table S5 in supplementary material).

The first strategy assesses production based on a shift in planting date. Eight scenarios were considered, including shifting forward and backward by 1, 2, 3 and 4 weeks from baseline (9 July). The second
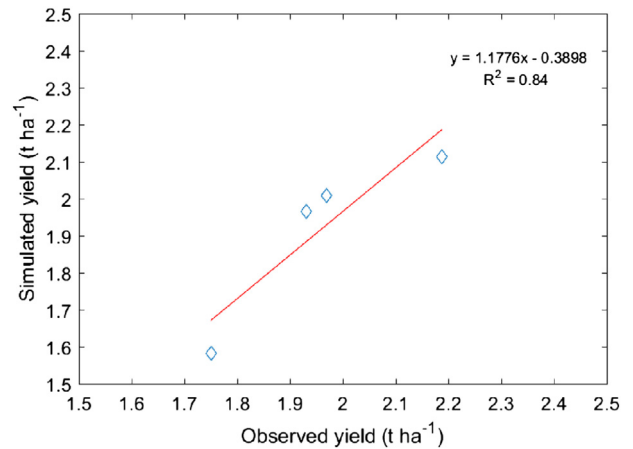
Fig. 5. Comparison between observed and simulated rainfed rice yields during calibration period (2009–2012).

adaptation strategy considers a shift in fertiliser application date under six cases, including forward and backward shifts by 1, 2 and 3 weeks from baseline (20 September). For the third adaptation strategy, five different fertiliser application dosages (7, 21, 28, 35 and 42 kg N ha^{-1}) were considered compared with baseline (14 kg N ha^{-1}). The fourth adaptation strategy varies the supply of irrigation water between 10 and 80 mm at 10 mm intervals during rice flowering stage (October), compared with no supply of water (rainfall).

The DSSAT model was used to simulate the rice yield for all the cases. The hypothesis of the study is that carrying out adaptation strategies will increase the rice production under climate change scenarios. Positive changes relative to the baseline rice production are worth considering as an adaptation strategy, while negative changes indicate infeasibility.

3. Results and discussion

3.1. Historical climate trends and future climate scenarios

Historical maximum and minimum temperatures show increasing trends. Thai Meteorological Department presented that the maximum and minimum temperatures increased 1.0 °C and 0.8 °C respectively from 1980 to 2004 in the basin. The results of bias-correction indicate that the average annual maximum and minimum temperature and standard deviation of corrected RCMs are similar to the observed data with high performance for all temperature stations as shown in Table S1 and S2 and Fig. S1 (Supplementary material). The maximum and minimum temperatures are expected to continually increase in the future. The average annual maximum temperature is expected to increase by up to 0.9, 1.2 and 1.6 °C under RCP4.5 scenario and 1.0, 1.8 and 2.8 °C under RCP8.5 scenario for 2030s, 2055s and 2080s respectively, and minimum temperature is also expected to increase by up to 0.9, 1.4 and 1.8 °C under RCP4.5 scenario and 1.1, 2.0 and 3.2 °C under RCP8.5 scenario for 2030s, 2055s and 2080s respectively, as shown in Fig. 3. The magnitude of increment under RCP8.5 scenario is higher than RCP4.5 scenario. Previous studies indicate similar results. The maximum and minimum temperature in Thailand might increase up to 3.04 and 3.99 °C under RCP8.5 scenarios for 2080s (2072–2099) (Shrestha

Table 4
Performance evaluation of the DSSAT model for the KDML105 rice variety.

Period	Year	Rice yield (t ha^{-1})		R^2	RMSE (t ha^{-1})	NSE	PBIAS	RSR
		Observation	Simulation					
Calibration	2009–2012	1.96	1.92	0.84	0.095	0.63	2.12	0.61
Validation	2013–2016	1.98	2.04	0.78	0.090	0.64	−2.67	0.60

et al., 2017), and 3.52 and 5.2 °C under 735 CO_2 concentration for 2080–2089 (Babel et al., 2011). The highest maximum temperature was 35.2 °C in April for baseline period, and it can be higher up to 36.4 and 38.1 °C under RCP4.5 and RCP8.5 scenarios for 2080s. The maximum and minimum temperature projected to be higher in every month during rainfed rice season (Fig. 7(a) and (b)). Temperature rise would increase the crop water requirement and irrigation water requirement (Boonwichai et al., 2018).

Historical annual rainfall (1980–2004) was varied from 1122 mm to 1705. The peak was in 2002. The average annual rainfall was 1391 mm. The average annual rainfall and standard deviation of corrected RCMs are close to the observed rainfall data for all rain gauge stations as shown in Table S3 and Fig. S1 (Supplementary material). The projected rainfall may not much change under climate change scenarios. Future rainfall may increase by 1394, 1468 and 1468 mm under RCP4.5 scenario and 1458, 1451 and 1447 mm under RCP8.5 scenario for 2030s, 2055s and 2080s respectively. However, the future rainfall will be more variability that can vary from 800 mm to 2300 mm. Past studies have reported that future rainfall may be both increased and decreased in many parts of Thailand. The future rainfall may vary from 2.6 to 45.2% in Northeast Thailand (Babel et al., 2011), may both increase and decrease in the Nam Oon Irrigation Project (Shrestha et al., 2017). This indicates that rainfall varies depending on several variables, including latitude, location, and topography. The monthly rainfall pattern is projected to shift forward. The rainfall during rainfed rice season may increase during June–August and decrease during September–November, as shown in Fig. 4(c).

3.2. DSSAT model calibration and validation

The DSSAT v4.6 crop simulation model was used to investigate the effect of climate change on rice yield and evaluate the potential adaptation strategies on rice production in the basin. The rice experiments data from Sakon Nakhon Rice research center of year 2009–2012 were used for model calibration and 2013–2016 for model validation. As farmers did not follow the cropping calendar suggested by the rice department (www.ricethailand.go.th), the 9 July was selected to represent the planting date for KDML105 rice variety in the basin for this study. The model was calibrated based on eight crop genetic coefficients parameters. Sensitivity analysis was carried out on eight parameters with the t stat and p-values tested. Abbaspour et al. (2015) suggests that a p-value of <0.05 (p-value < 0.05) is the generally accepted point at which to reject the null hypothesis. The genetic coefficient was altered by ±30% of the available default in the DSSAT. Seven parameters were the most influential on rice yield, as shown in Table 3. Shrestha et al. (2017) presented two sensitive parameters including P2O and G2. The values of genetic coefficient parameters were adopted by Shrestha et al. (2017), Babel et al. (2011) and Buddhaboon et al. (2004).

The model performance evaluation indicates good performance (Table 4). The R^2 values is 0.84 and 0.78 for the calibration and validation periods respectively, with R^2 values >0.5 considered acceptable (Moriasi et al., 2007). The NSE is 0.63 and 0.64 for the calibration and validation periods respectively within satisfactory range. The average magnitude (PBIAS) fell within the very good range during both calibration and validation periods. The RSR is 0.61 and 0.60 for the calibration and validation within range from satisfactory to good. The simulated rice yields show the similar results with the observed rice yields, as shown in Fig. 5. Therefore, the model is suitable for simulating the future rice production under climate change conditions in the basin.

3.3. Climate change impacts on rice yield

Future rice yield was projected under climate change scenarios for the three future periods. The study assumed that the field management practices will not change in the future, making climate the only variable. The rice yield was 1.97 t ha^{-1} for 2009–2016. Rice department (www.

ricethailand.go.th) reported that the potential yield of KDML105 is 2.27 t ha^{-1}. The future rice yield is expected to reduce by 1.4, 7.8 and 11.1% under RCP4.5 scenarios and 1.2, 10.6 and 14.7% under RCP8.5 scenario for 2030s, 2055s and 2080s respectively, indicating that the projected rice yield under climate change scenarios is reducing and lower than the potential yield. This could be attributed to the rise in temperature, which leads to higher evaporation and transpiration rates, as well as future crop water requirement. In contrast, future annual rainfall may be unchanged, and rainfall patterns are expected to shift forward, hence crop water shortage is expected to occur in the future due to reducing water availability during rainfed rice season. The crop water requirement and irrigation water requirement may be higher in future which can lead to lower rice yield (Boonwichai et al., 2018). Temperature rise combined with uncertainty in rainfall in the future will have significant impacts on rice production.

3.4. Adaptation strategies for rainfed rice yield

Based on the simulation results, the future rice yield without adaptation strategies is expected to decrease under climate change scenarios. The four adaptation strategies including change in planting date, change in fertiliser application date and dose, and supplying irrigation water proposed by four hundred farmers in the basin were evaluated to mitigate the effects of climate change on rice yield.

Table 5
Summary of the KDML105 rice yield of four adaptation strategies under RCP4.5 and RCP8.5 scenarios for 2030s, 2055s and 2080s.

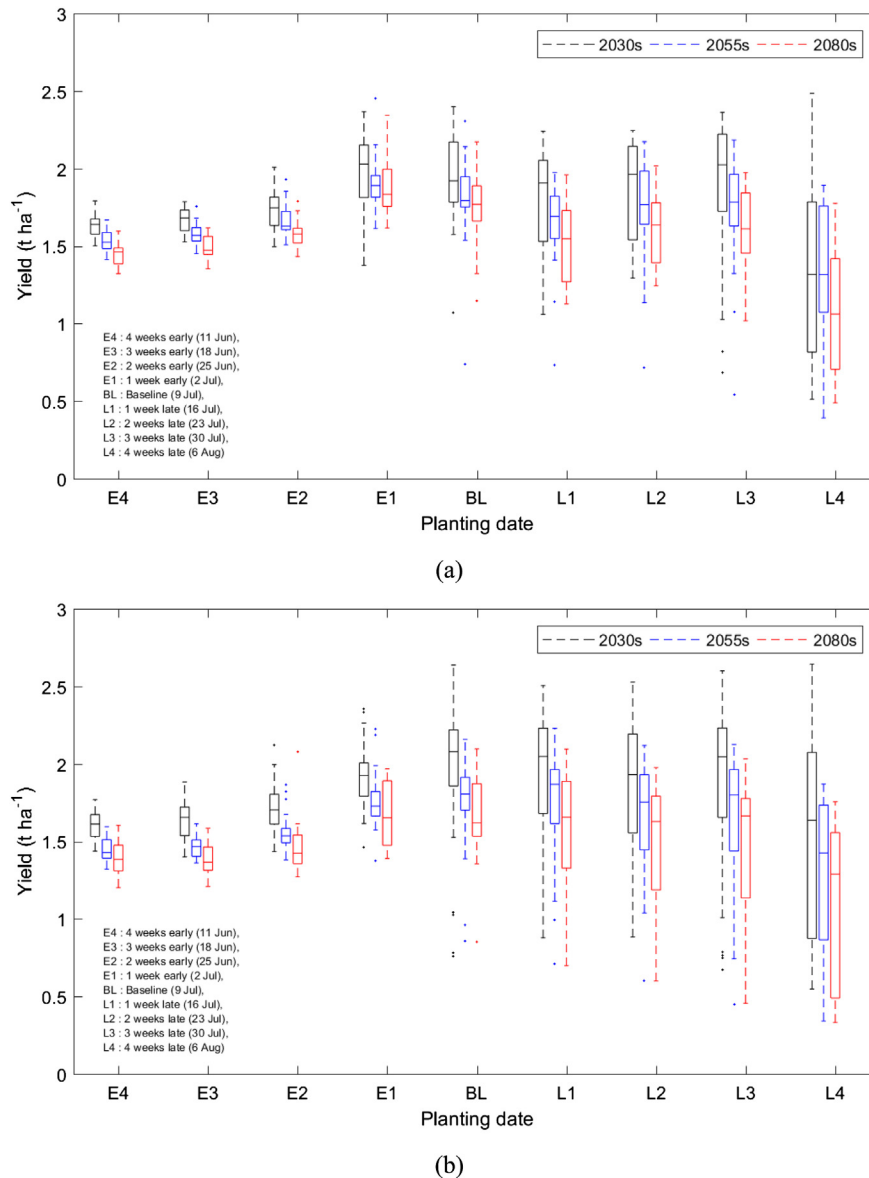| Adaptation strategies	Date	Rice yield (t ha^{-1})					
		RCP4.5			RCP8.5		
		2030s	2055s	2080s	2030s	2055s	2080s
Change in planting date							
Shift forward 4 weeks	11 Jun	1.64	1.53	1.44	1.61	1.45	1.39
Shift forward 3 weeks	18 Jun	1.67	1.57	1.49	1.64	1.47	1.39
Shift forward 2 weeks	25 Jan	1.72	1.66	1.58	1.72	1.56	1.46
Shift forward 1 week	2 Jul	1.97	1.90	1.89	1.91	1.77	1.67
Baseline planting date	9 Jul	1.94	1.82	1.75	1.95	1.76	1.68
Shift backward 1 week	16 Jul	1.79	1.66	1.52	1.91	1.73	1.60
Shift backward 2 weeks	23 Jul	1.87	1.73	1.61	1.88	1.64	1.49
Shift backward 3 weeks	30 Jul	1.87	1.75	1.60	1.85	1.63	1.40
Shift backward 4 weeks	6 Aug	1.36	1.32	1.10	1.52	1.28	1.07
Change in fertiliser application date							
Shift forward 3 weeks	30 Aug	1.89	1.83	1.80	1.91	1.77	1.69
Shift forward 2 weeks	6 Sep	2.00	1.94	1.95	1.99	1.79	1.74
Shift forward 1 week	13 Sep	2.06	1.94	1.93	1.98	1.77	1.71
Baseline fertiliser date	20 Sep	1.94	1.82	1.75	1.95	1.76	1.68
Shift backward 1 week	27 Sep	1.97	1.86	1.84	1.93	1.77	1.72
Shift backward 2 weeks	4 Oct	1.77	1.68	1.62	1.75	1.62	1.47
Shift backward 3 weeks	11 Oct	1.55	1.46	1.38	1.54	1.39	1.28
Change in fertiliser application dose							
7 kg N ha^{-1}	(0.5 times)	1.68	1.62	1.59	1.68	1.55	1.46
Baseline (14 kg N ha^{-1})	(1.0 times)	1.94	1.82	1.75	1.95	1.76	1.68
21 kg N ha^{-1}	(1.5 times)	1.58	1.59	1.35	1.67	1.42	1.41
28 kg N ha^{-1}	(2.0 times)	1.53	1.61	1.29	1.68	1.46	1.34
35 kg N ha^{-1}	(2.5 times)	1.38	1.54	1.19	1.50	1.34	1.22
42 kg N ha^{-1}	(3.0 times)	1.20	1.46	1.03	1.33	1.24	1.13
Irrigation supply							
Baseline (no irrigation, only rainfall)		1.94	1.82	1.75	1.95	1.76	1.68
10 mm		1.99	1.87	1.82	2.01	1.80	1.76
20 mm		2.08	1.96	1.95	2.10	1.90	1.86
30 mm		2.18	2.06	2.06	2.15	1.96	1.93
40 mm		2.21	2.09	2.09	2.19	2.02	1.97
50 mm		2.22	2.11	2.10	2.21	2.06	1.99
60 mm		2.23	2.12	2.11	2.22	2.07	2.01
70 mm		2.23	2.13	2.11	2.23	2.08	2.01
80 mm		2.23	2.13	2.11	2.23	2.08	2.01

3.4.1. Change in planting date

For the first adaptation strategy, shifting the planting date resulted in increased rice yield under RCP4.5 scenario but decreased rice yield under RCP8.5 scenario. Planting at least two weeks early would cause more than a 10% reduction while planting four weeks late could cause the yield to reduce by >20% under both RCP scenarios. Comparing the two RCP scenarios, loss in yield is more serious for RCP8.5 with early planting dates, and later planting cause greater yield loss under the RCP4.5 scenario. The only increase in rice yield observed under this adaptation option is an increase by 1.6, 4.5 and 7.7% for 2030s, 2055s and 2080s compared with without shifting planting date when the planting date is shifted forward by one week under RCP4.5 scenario, as shown in Table 5 and Fig. 6.

Change in rainfall has significant influence on rice yield (Boonwichai et al., 2018). Future rainfall patterns are expected to shift earlier hence shifting the planting date forward would avoid the water deficit period. However, this would coincide with periods of high temperature which will potentially increase crop water requirement. Studies by Babel et al. (2011) and Dharmarathna et al. (2014) suggest that shifting the planting date forward by one month can increase rice yield, while the study by Reda et al. (2015) recommends an adjustment in the crop calendar for farmers along the Upper, Middle and Lower Ping River Basin. These studies employ the CERES-rice crop growth model, DSSAT model, and multiple regression models, respectively. The difference in results could be attributed to the varying analysis methods, study assumptions, climate models, and emission pathways considered, and local conditions in the study areas.

3.4.2. Change in fertiliser application date

Environmental conditions have a significant influence on rice yield, especially during its growth stage. Applying fertiliser at the proper time could increase crop yield. The results indicate that fertiliser should be applied one week early for 2030s and 2055s and two weeks early under RCP4.5 scenario and two weeks early for three future periods under RCP8.5 scenario. The rice yield can increase by 5.8, 7.0 and 11.6% under RCP4.5 scenario, and 2.0, 1.6 and 3.9% under RCP8.5 scenario for 2030s, 2055s and 2080s respectively, as shown in Table 5 and Fig. 7. Shifting fertiliser application date will increase the fertiliser

Fig. 6. Rainfed rice yield for adaptation strategies of change in planting date (shift forward 1, 2, 3, 4 weeks, baseline, and shift backward 1, 2, 3, 4 weeks) under (a) RCP4.5 and (b) RCP8.5 scenarios for 2030s, 2055s and 2080s.
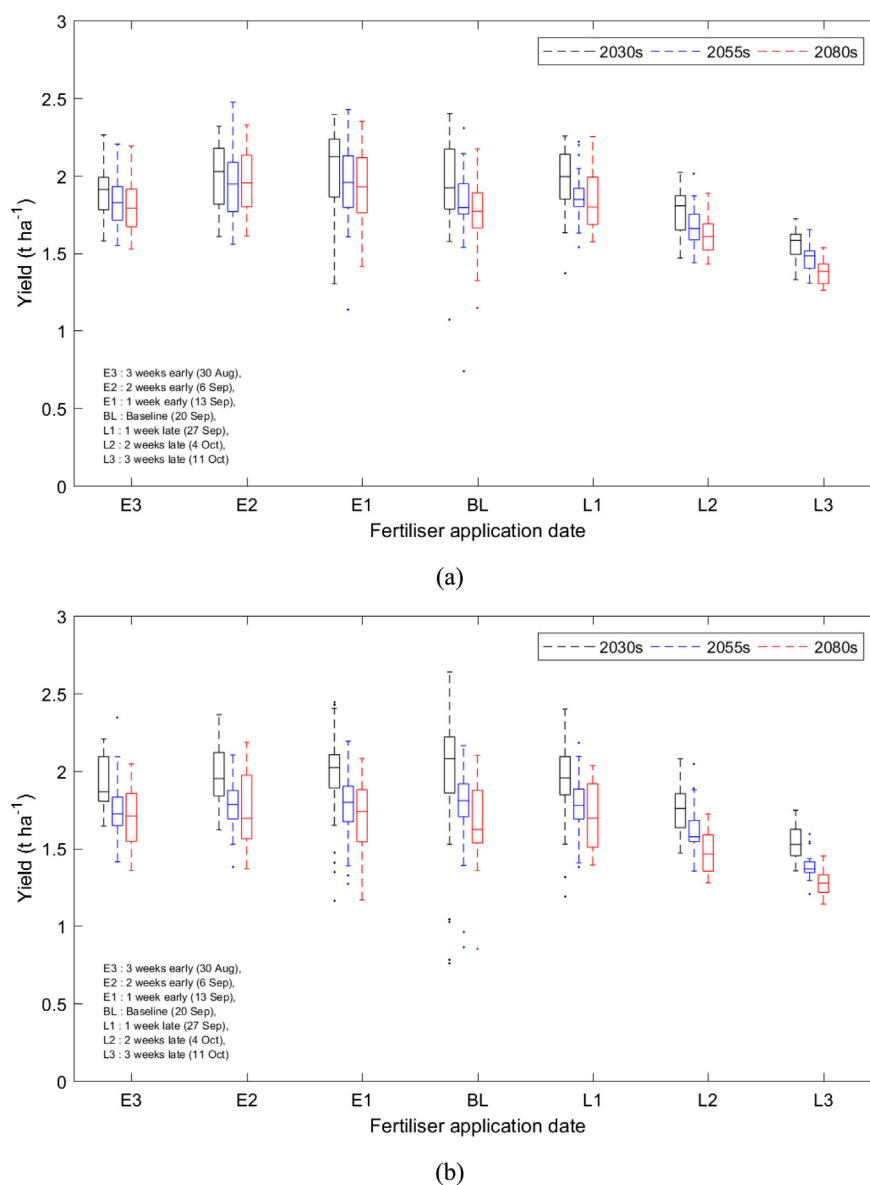
Fig. 7. Rainfed rice yield for adaptation strategies of change in fertiliser application date (shift forward 1, 2, 3 weeks, baseline, and shift backward 1, 2, 3 weeks) under (a) RCP4.5 and (b) RCP8.5 scenarios for 2030s, 2055s and 2080s.

efficiency due to shift in rainfall which increasing the soil moisture. Babel et al. (2011) suggest that shifting the fertiliser application date forward will reduce the effect of rice yield under climate change conditions. To reiterate, the obtained results indicate that shifting the fertiliser application calendar is a viable adaptation option, but the duration of shift is largely dependent on local conditions and crop variety.
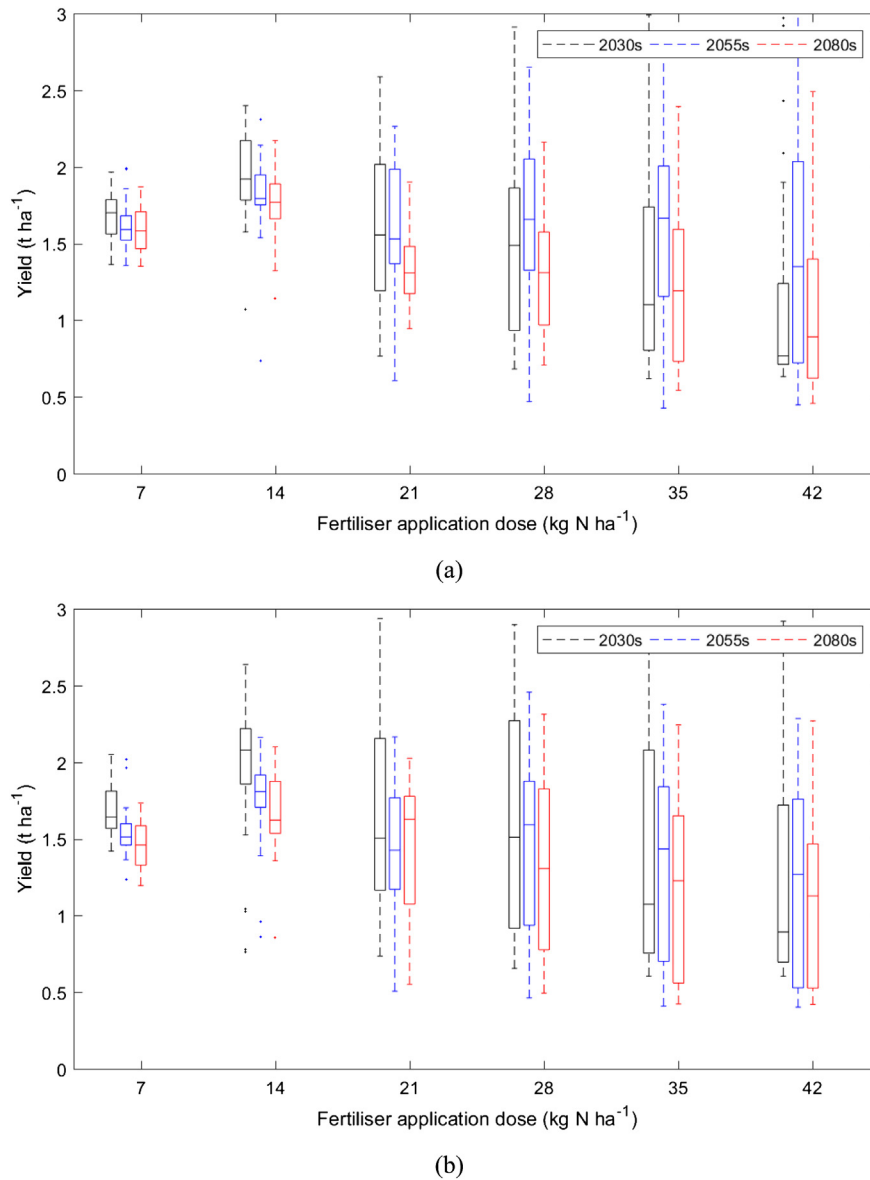
3.4.3. Change in fertiliser application dose

Varying the fertiliser dosage resulted in lower rice yield for all cases under both scenarios, as shown in Table 5 and Fig. 8. Although Babel et al. (2011) suggest that increasing the fertiliser application rate will increase rice yield in the future, proper fertiliser application dosage is essential for crop growth and yield. Guo et al. (2017) illustrate that increasing yield through higher fertiliser application rates will only be possible if the lack of nutrients is one of the main limiting factors. Other factors include soil conditions and long-term fertiliser accumulation. Excessive fertiliser dosage can lead to toxicity which in turn reduces crop growth and may even result in plant death (Kenzie, 1998). In addition, leaching and runoff will bring the fertiliser through surface water and groundwater which will affect water quality, it can be harmful to human health and pose a threat to the environment.

3.4.4. Supplying irrigation water

In contrast to the other three adaptation options, the supply of irrigation water resulted in higher rice yield. When 60 and 70 mm of water is supplied under RCP4.5 and RCP8.5 scenarios respectively for three future periods, rice yield can significantly increase between 15 and 20%, as shown in Table 5 and Fig. 9. This adaptation option is favourable as it can counter the negative impact of climate change. Based on the projected results, temperature rise combined with a decrease in rainfall could lead to water shortage during the rice growing period, reducing rice yield. Supplying sufficient water can optimize rice yield to its potential, based on the simulation results. In contrast, the rice yield might not reach the potential yield for 2055s and 2080s due to high temperature. The suitable temperature for rice growth is between 25 and 33 °C (NATRES, Faculty of Natural Resources, 2018). Temperatures above 35 °C lead to high crop vulnerability and could affect the ripening stage, significantly reducing rice production (Tipparak
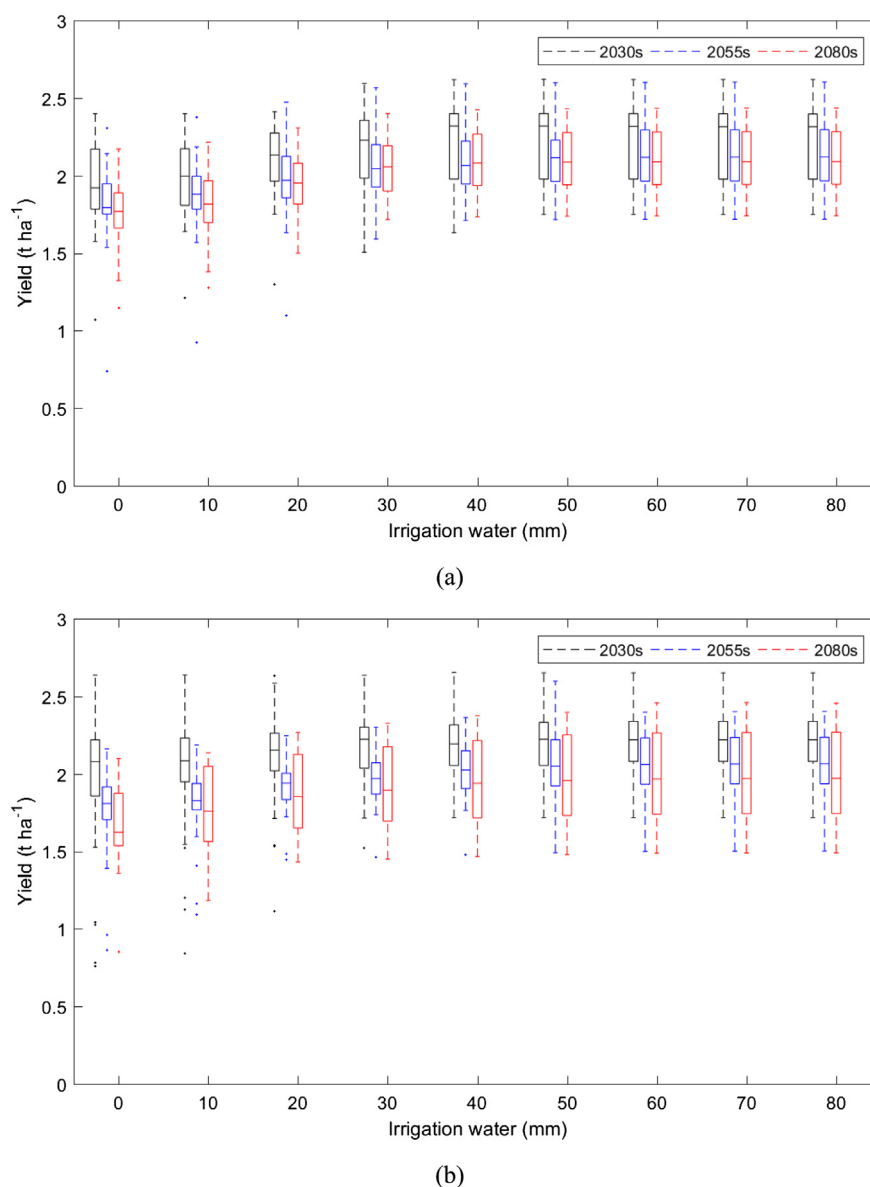
(a)

(b)

Fig. 8. Rainfed rice yield for adaptation strategies of change in fertiliser application dose (7, 14, 21, 28, 35 and 42 kg N ha^{-1}) under (a) RCP4.5 and (b) RCP8.5 scenarios for 2030s, 2055s and 2080s.

and Aroonrungsikul, 2011). Contrary to expectations, although the crop is rainfed, the performance can be improved if additional water is provided. A plateau in yield is observed when water is no longer a contributory factor in limiting growth and yield. The sources of water such as river, pond and groundwater should be considered. The agriculture production planning model may be required to optimize the water management and environmental protection. Bournaris et al. (2015) suggested the optimization multicriteria mathematical programming (OMMP) model which can reduce fertilisers, water and labour uses.

4. Conclusion

The top-down and bottom-up approaches were applied for climate change impact assessment and adaptation measurement evaluation in this study. Future rice yield under climate change scenarios (RCP4.5 and RCP8.5 scenarios) in Songkhram River Basin, Thailand was investigated using the DSSAT crop simulation model. The future climatic variables (maximum and minimum temperature, and rainfall) were projected by an ensemble of four RCMs (ACCESS1.0-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM, ICHEC-EC-EARTH-SMHI-RCA4 and MPI-

ESM-LR-CSIRO-CCAM) to address the uncertainty. The Quantile mapping technique was applied to correct the RCMs. Four adaptation strategies including change in planting date, change in fertiliser application date and dose, and supplying irrigation water were evaluated for 2030s, 2055s and 2080s. Future maximum and minimum temperatures are expected to rise by 1.6 and 1.8 °C under RCP4.5 scenario and 2.8 and 3.2 °C under RCP8.5 scenario for 2080s. Annual rainfall may be unchanged in the future but rainfall patterns will shift earlier. Climate change may reduce the future rice yield by 11.1 and 14.7% under RCP4.5 and RCP8.5 scenarios respectively for 2080s. The combined effects of temperature rise and uncertainty in future rainfall may be unfavorable to rice yield. Evaluating the four adaptation strategies yielded the following results. First, shifting planting date forward one week may increase the rice yield by 1.6, 4.5 and 7.7% for 2030s, 2055s and 2080s respectively under RCP4.5 scenario, while it is best not to alter the planting calendar under RCP8.5 scenario for three future periods. Second, shifting fertiliser application date forward one week for 2030s and 2055s, and two weeks for 2080s RCP4.5 scenario and two weeks for all future periods under RCP8.5 scenario can increase the rice yield by 11.6 and 3.9% under RCP4.5 and RCP8.5 scenarios respectively for

(a)

(b)

Fig. 9. Rainfed rice yield for adaptation strategies of supplying irrigation water (only rainfall, 10, 20, 30, 40, 50, 60, 70 and 80 mm) under (a) RCP4.5 and (b) RCP8.5 scenarios for 2030s, 2055s and 2080s.

2080s. Third, an adjustment in fertiliser application dose may result in decreased future rice yield for both scenarios. Finally, supplying irrigation water during rice flowering stage could significantly increase rainfed rice yield to its potential yield capacity. Results demonstrated that rice yield will be affected by climate change and adaptation strategies have to be considered seriously. Although the supply of irrigation water can aid the production for rainfed rice, other concerns such as the source of water are involved. The feasibility of adaptation actions would depend largely on available resources and mindset of farmers. Further work is warranted in exploring a combination of adaptation strategies and management plans. DSS systems may be required to manage environmental-fertiliser-production.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.10.201.

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